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A 16 FOOT DIAMETER MILLIMETER WAVELENGTH ANTENNA SYSTEM, ITS CHARACTERISTICS AND ITS APPLICATION

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Technical Report No. I

Grant NsG-432

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D. C.

RC #2

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ABSTRACT

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The 16 foot diameter antenna system at the Electrical Engineering Research Laboratory of The University of Texas has characteristics suited for the spectroscopic measurement of millimeter wavelength emission and absorption of the bodies of the solar system and of galactic and extragalactic sources.

The efficiencies of the antenna at the frequencies of 35 and 94 Gc are 58% and 52%, respectively, corresponding to gain and beam widths of 63 db and 0.118 degrees at 35 Gc; 68.5 db and 0.060 degrees at 70 Gc; and 70.9 db and 0.048 degrees at 94 Gc. The first side lobes and other side lobes are -18 db and -25 db, respectively, over the 35 to 94 Gc frequency interval.

The polar axis is precision driven at rates between 0.001 and 4° per minute and the polar and declination beam positioning accuracy is 0.01° rms in a 60° zenith cone angle.

The parameter of observing will allow brightness temperatures to be determined within ± 20%. Observations below altitude angles of approximately 45° (between meridian declinations of -15° and +80°) will suffer from absorption in the earth's atmosphere and therefore will be less accurate. Measurements will be restricted primarily to the window frequencies below 40 Gc, 68 to 116 Gc, 125 to 160 Gc, and 220 to 260 Gc. Operational 10 mc IF bandwidth 35, 70, and 94 Gc radiometers are currently in use with the

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antenna. A 10 mc IF bandwidth, 140 Gc radiometer and 2 Gc IF bandwidth, 35, 70, and 94 Gc radiometers are being assembled.

The 70 Gc radiation temperatures of Jupiter and the earth's moon have been measured. The brightness temperature of Jupiter was 112 ± 22°K and the maximum brightness temperature contour of the moon was 270°K. Relatively higher emission temperatures are observed from the maria and the craters of Capernicus and Tycho than from surrounding areas.

AUTHOR

I. INTRODUCTION

This report describes the 16 foot diameter millimeter wavelength antenna system at the Electrical Engineering Research Laboratory of The University of Texas, its characteristics and its applications.

Having been engaged in the investigation of the emission and absorption of millimeter wavelengths (30 to 300 Gc) since 1952 under sponsorship of the Department of Defense, the usefulness of a millimeter wavelength antenna of sufficient capture area to bring the radiation levels of the planets of the solar system within the measuring threshold of conventional radiometers was apparent.[1,2,3] Such an antenna would also enhance the resolution of emission from the brighter bodies of the solar system over that of the available 5 and 10 foot diameter antennas and advance the "seeing" threshold of galactic and extragalactic sources.[4,5] Funds to fabricate such a millimeter antenna were solicited and design and construction techniques studied.

The National Aeronautics and Space Administration's Advisory Group on Electromagnetic Space Experiments recommended that such an antenna be constructed to obtain reference data on millimeter radiation levels of the solar system. The parabola was to operate over the wavelength interval between the 60 Gc complex of oxygen lines and the 183 Gc water vapor line and have an effective aperture in excess of 10 square meters at 70 Gc. The antenna pattern was to be well defined and stable over this frequency interval in order that brightness could be accurately evaluated.

Since the primary applications of the antenna system were astronomical observations, an equatorial mounting was selected. Variable drive rates were to allow the information bandwidth to be selectible and optimized for the particular observation. The pointing accuracy of the antenna beam was to be 1/10 the half power beamwidth, and the drives were to permit source tracking within 1/10 of the beamwidth over a one hour period. It was also specified that the reflector be swept with warm air when observing to prevent dew from forming on the reflector surface.

Millimeter wavelengths have marked characteristics which in many ways associate them more nearly with optical wavelengths than with the normal radio wavelengths. In general, when the weather is not suitable for optical observations, it is not good for millimeter observations. The variability and uncertainty of cloud opacities severely restrict absolute millimeter brightness measurements, and observations through rainfall are prohibited.[7] The use of an airdome was negated because of its obstruction of both easy optical confirmation of the antenna pointing and of the millimeter wavelengths themselves by attenuation, reflection, and phase-front distortion. To protect the reflecting surface of the parabola and the other components of the system from the environment, an astrodome similar in design to that used with optical telescopes was selected.

While mechanical means are available for measuring the accuracy of the reflector surface and indeed must be used in fabricating the parabola, proof of performance of the antenna was prescribed in terms of the radio frequency characteristics of the antenna.

The site of the antenna system, 30°23'17" north longitude, 97°43'37" west latitude, at the Balcones Research Center of The University of Texas was convenient to the Electrical Engineering Research Laboratory and graduate students of The University of Texas.

The Western Development Laboratories of the Philco Corporation, a subsidiary of the Ford Motor Company, was selected to fabricate and install the millimeter wavelength antenna. The antenna system was completed 1 June 1963, fifteen months after the contract was awarded.

II. MECHANICAL CHARACTERISTICS OF ANTENNA SYSTEM

Photographs of the operational antenna system are shown in Figures 1 and 2. The concrete of the two-pedestal mount extends nine feet below the surface of the earth to a 100 square foot base in unweathered limestone. Extending above the concrete pillars are steel plate towers holding the polar axis bearings. The towers are adjustable by captive screws in both azimuth and elevation to allow the polar axis to be aligned with the earth's axis. The fork of the declination axis is attached to a continuous shaft through the polar axis.

Both axes are driven by opposing torque motors, the driving torque being derived from an unbalance of the individual motor torques. The declination axis is positioned by synchro command with resolver and position encoder displayed in increments of ± 0.001 degrees. The polar axis is positioned by signals of error increments exceeding ± 0.001 degrees between the position command and the polar axis position encoder. Precision and course drive rate command signals for the polar axis are derived from a crystal controlled oscillator and an adjustable rate slew control. Both axes have velocity and position limiting switches to prevent accidental damage. The controls, logic, amplifiers, position display, etc. are located in relay racks at the north point of the astrodome housing.

The reflector form is made up of 16 each gores, each gore composed of two 0.040 inch thick stretch formed invar sheets separated by 1 1/4 inch thick aluminum corrugation. The reflector backup structure is of rectangular invar tubing. The 16 each sections were welded together to form a continuous parabolic invar sheet surface upon which an epoxy resin was swept and figured. The radio frequency reflecting surface on the epoxy consists of a 40×10^{-6} inch thick electro-deposited gold surface over a chemically deposited layer of silver.

The backup structure of the reflector is attached by four cap screws to each of the arms of the declination axis fork. There are three openings in the reflector, one in the center for the warm air output and two others approximately four feet from the center for bore-sighted optical telescopes. Four spars of 1 1/2 inch diameter invar tubing suspend a 5 inch diameter invar ring feed support approximately 6 inches beyond the prime focus of the parabola.

A summary of the mechanical characteristics of the 16 foot antenna system are as follows:

Reflector surface accuracy	.003 inches
Feed support stability	± .003 inches
Polar axis alignment	1 sec. of arc
Declination axis orthogonality	3 sec. of arc
Axis drive rates	0.001 to 4.0 deg/min
Slew rates	1 deg/sec
Axis position readout	0.001 deg

A steel astrodome 35 feet in diameter covers the parabolic reflector, pedestal, antenna position control, radiometers and other assorted components on a floor area of 300 square feet. In conjunction with the 1/5 rpm rotatable dome, a 19 foot wide shutter opening permits full hemispherical viewing.

The antenna system is operational under the following environmental conditions:

Temperature	0°F to 110°F
Humidity	0 to 95% rel.
Wind	0 to 30 mph

III. RADIO FREQUENCY CHARACTERISTICS OF ANTENNA SYSTEM

The 35, 70 and 94 Gc antenna characteristics were determined by observing coherent radiation from a distance of 38,200 feet.[8] A profile of the propagation path between The University of Texas tower and the antenna is shown in Figure 3. The gain of the antenna at the three frequencies was determined by measurement of the 16 foot antenna signal strength relative to that of standard gain horn antennas.

The 70 Gc receiver head and standard gain horn antenna are shown in Figure 4, mounted in the antenna spar ring. Wave guide horns at the prime focus accept -10 db peripherially tapered energy from the reflector. A wave guide switch transfers the receiver input between the standard horn and the 16 foot antenna.

Vertical fields, as seen by the standard horn antenna, were measured and the direct field strengths evaluated at each of the three frequencies. The 70 Gc signal strength versus elevation above the ground at the 16 foot antenna is shown in Figure 5, with the position of the standard horn antenna during the gain measurements indicated. The calculated major reflecting area of the multipath radiation indicated by the vertical signal profile was slightly greater than 0.2° off the direct path or approximately 75 feet below the direct ray at a distance of 3.5 miles from the antenna. Reflection coefficients were 0.23, 0.17 and 0.15, respectively, for the frequencies of 35, 70 and 94 Gc. The high resolution of the 16 foot antenna beam minimizes the effects of the reflected signal and it is, therefore, of small consequence in the immediate vicinity of the major lobe.

The E and H plane 35, 70 and 94 Gc antenna patterns are shown superimposed in Figures 6 and 7, respectively. Pattern and gain measurements were made with the feed optically centered on the geometric major axis of the antenna and adjusted along the major axis, axially to the focal plane, for maximum signal levels over the 38,200 foot range. The coma indicated on all the patterns can be corrected by adjustment of the feed laterally in the focal plane.

The radio frequency characteristics are as follows:

	35	70	94	
Gain	63	68.5	70.9	± 0.3 decibels
Efficiency	58	54	52	per cent
H plane	.118	.062	.046	deg. half pwr.

Beam width				
E plane	.119	.060	.050	deg. half pwr.
First side lobe	-23	-17	-18	decibels
Other side lobe	-30	-25	-28	decibels

While there was no observable change in the 70 Gc antenna gain and beamwidth or the apparent position of the antenna beam as reflected in the position readout over the approximately 10 month period between the performance test of April, 1963 and the performance tests of February, 1964, the side lobes have become degraded. The E plane and the H plane patterns of April, 1963, and February, 1964, are shown respectively superimposed in Figures 8 and 9.

IV. MILLIMETER RADIOMETERS

The radiometers that have been assembled for use with the antenna systems are relatively narrow bandwidth Dicke type utilizing synchronous detection at 30 cps.[3,8] The mechanical modulators or choppers prior to the heterodyne crystal mixers are preceeded by ferrite isolators and wave guide switches to the feed horn. Local oscillators, crystal mixers and IF amplifiers are located in the radiometer heads with the other millimeter wavelength components.

To maintain the feed positioned within ± 0.003 inches for all altitudes of the antenna, the radiometer heads are weighted to produce a centrally located 50 foot pound bending moment on the spar ring. The alignment of the antenna feeds by the bearing surface between spar ring and the housing of the heads is sufficient to maintain the antenna beam positioning when the radiometers are interchanged.

A photograph of the 35, 70 and 94 Gc mc/s IF bandwidth radiometer heads is shown in Figure 10. The waveguide feed horns are in the foreground. A gas noise source is mounted on the 35 Gc radiometer and a thermally variable waveguide termination is mounted on the 94 Gc radiometer. The upper shell of the 70 Gc radiometer is removed, exposing the millimeter waveguide components. Common IF amplifier synchronous detector, power supply and analog-digital recording assembly are used with the heads. Both gas noise tubes and thermally variable waveguide termination are used to calibrate the radiometers through the waveguide switches.

The radiometers have the following rms temperature measuring uncertainties for one second time constants:

35 Gc	1°C
70 Gc	5°C
94 Gc	7°C

A narrow band 140 Gc radiometer is being assembled; and the component parts of wide band, 2 Gc, radiometers are being procured for assembly.

V. MILLIMETER TELESCOPE CHARACTERISTICS AND APPLICATIONS

The oxygen and water vapor zenith attenuation through the earth's atmosphere between the frequencies of 10 and 400 Gc, based on both measured and calculated values, is shown in Figure 11.[9] Frequencies of 35, 70, 94 and 140 Gc are located at absorption minima. The absorption through a standard atmosphere containing 7.5 gms of water vapor at sea level is shown in Figure 12 at the frequencies of 35, 70, 94 and 140 Gc as a function of altitude angle and the millimeter telescope celestial meridian declination. The attenuation is such that the normal observing period would be confined to ± 2 hours of the meridian at 70 Gc and ± 3 hours at 35, 94 and 140 Gc.

The inherent restrictions due to atmospheric gas absorption alleviate the atmospheric refraction problems experienced at altitude angles less than 30°.[10, 11] Measured values of refraction during summer months at the location of the telescope are shown in Figure 13.

The antenna temperatures as a fraction of the brightness temperature of Venus, Saturn and Jupiter are shown in Figure 14 for calendar 1964. The 70 Gc curves shown of fractional temperatures versus time is one of an identical family of curves at each frequency for each planet. This summation of "seeing" is based upon the antenna efficiency, the antenna beamwidth, the average attenuation through the atmosphere on the meridian, and the optical diameters of the planets. A flux density of 1×10^{-24} watts meter^{-2} cycle second^{-1} will produce a 1°C change in the antenna temperature.

The performance of the 16 foot diameter millimeter telescope opens a new fraction of the electromagnetic spectrum to better and higher resolved viewing of solar system, galactic, and extragalactic sources. In conjunction with side bandwidth radiometers, the brightness temperature of the planets Venus, Mars, Saturn and Jupiter can be determined at band frequencies of 35, 70, 94, 140 Gc and probably 240 Gc. From such measurements and the results of measurements at lower frequencies, the gross physical features of both planetary surfaces and atmospheres can be hypothesized.[12,13,14,15,16,17] With narrow band radiometers molecular emission and absorption line spectra frequencies can be examined and the detail of planetary atmosphere hypothesized.[18,19] Both wide and narrow band spectroscopy will be limited by the emission and absorption of water vapor and oxygen in the earth's atmosphere. The filtering spectrum of the earth's atmosphere, however, will not restrict the measurement of the spectra of a multitude of other gases.[18,19]

The thermal diffusity of the surface materials of solar bodies with tenuous atmospheres, in particular the earth's moon, can be deduced under the influence of solar heating from the observed brightness temperatures at different frequencies.[4,20,21,22] Such measurements give a temperature profile in depth versus wavelength of the frequencies observed.

The high resolution of the 16 foot antenna will permit the differentiation of brightness temperatures over extended sources, such as the moon and the sun. The celestial sphere can be surveyed and, on the basis of brightness versus frequency, a differentiation made between thermal and nonthermal galactic and extragalactic emitters.[23]

An example of a planetary brightness temperature measurement at 70 Gc is shown in Figure 15.[24,25,26] The series of points are individually the summation of 55 antenna temperature measurements by hour angle scanning Jupiter. The continuous curve is the calculated response of the antenna, when corrections for antenna efficiency, antenna beamwidth, and atmospheric opacity are applied, to a point source brightness temperature of 112°K.[27,28]

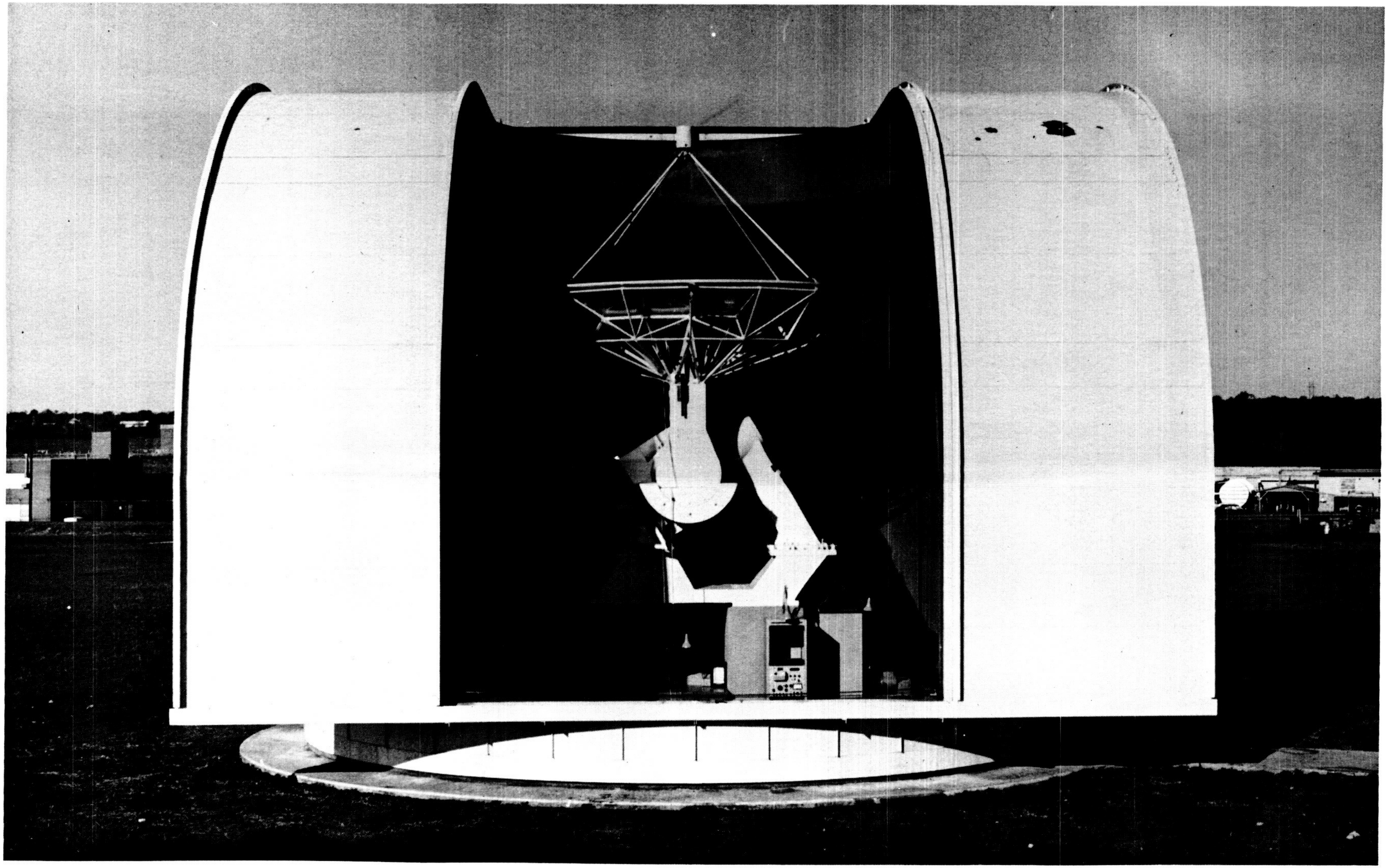
Temperature contours of 70 Gc emission over the surface of the moon are also shown in Figure 15 as an example of the resolution of brightness temperatures from extended sources.

VI. CONCLUSIONS

The 16 foot antenna system has the desired long term stability of antenna gain, beam shape and beam positioning accuracy. In conjunction with both narrow and wide bandwidth radiometers, spectroscopic investigations of millimeter wavelength emission and absorption of the bodies of the solar system and of galactic and extragalactic sources can be conducted at atmospheric minima absorption frequencies. Such an investigation is currently in progress at the frequencies of 35, 70 and 94 Gc.

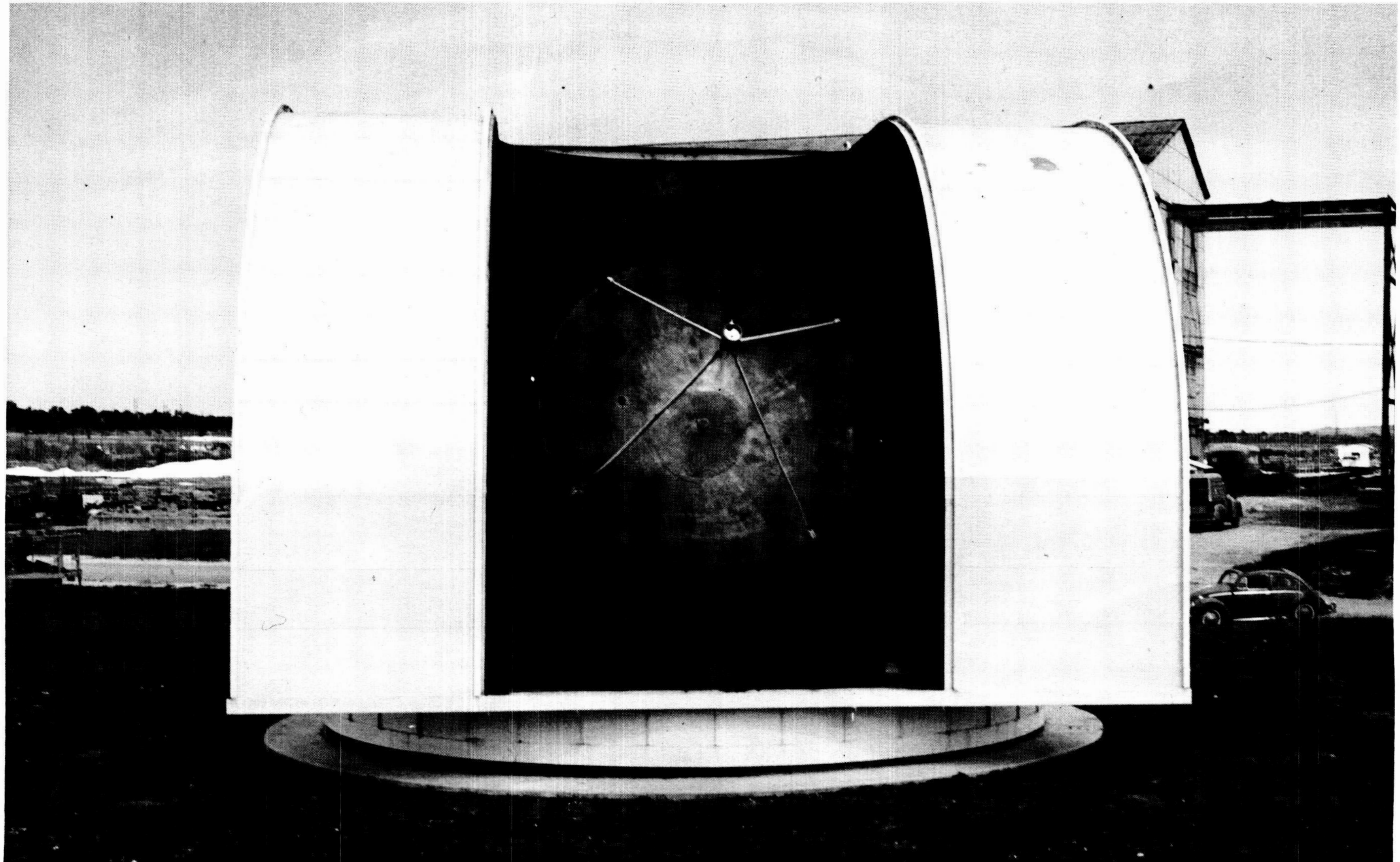
Acknowledgement

The antenna system was procured with support of NSF Grant NSF G-13240 under NASA Contract NASr-87. The measurements described in this article and the continuing research with the telescope are supported by NASA Grant NsG-432.



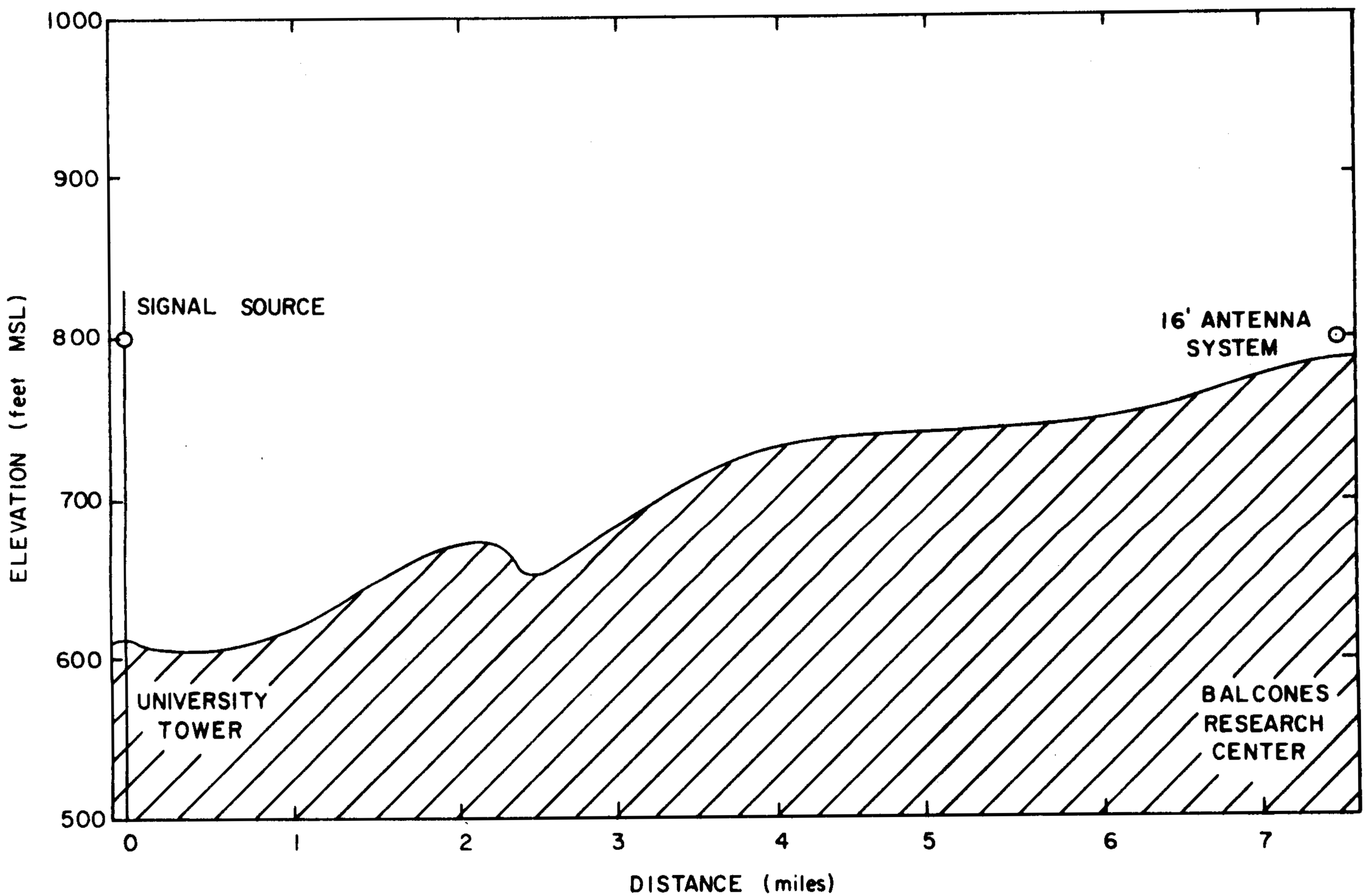
A PHOTOGRAPH SHOWING THE TWO PEDESTAL MOUNT, THE POLAR AND DECLINATION AXES AND THE PARABOLA BACKUP STRUCTURE OF THE 16 FOOT ANTENNA SYSTEM

FIG. 1.



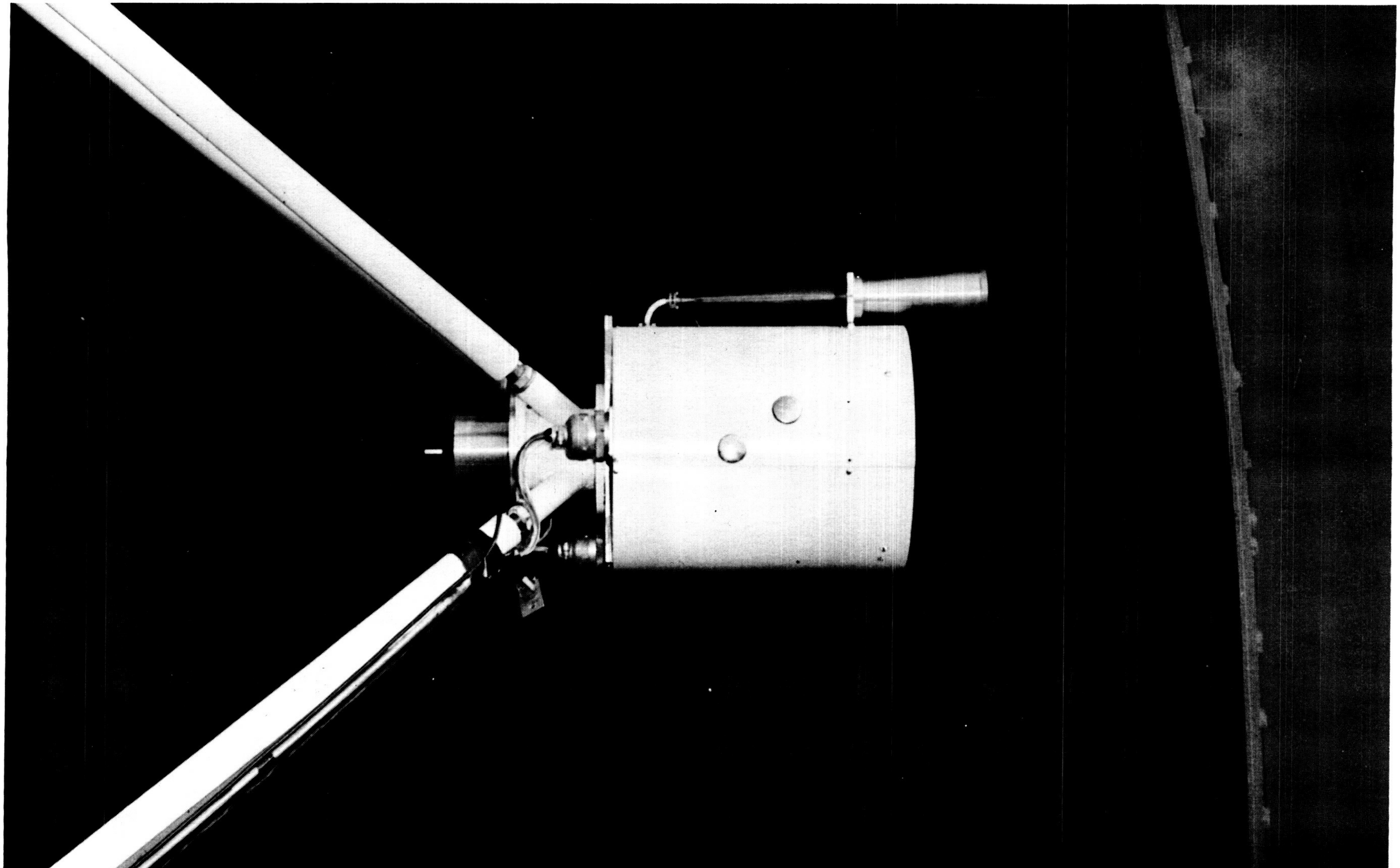
A PHOTOGRAPH OF THE ANTENNA SYSTEM SHOWING THE FACE OF THE PARABOLA AND THE ASTRODOME

FIG. 2.



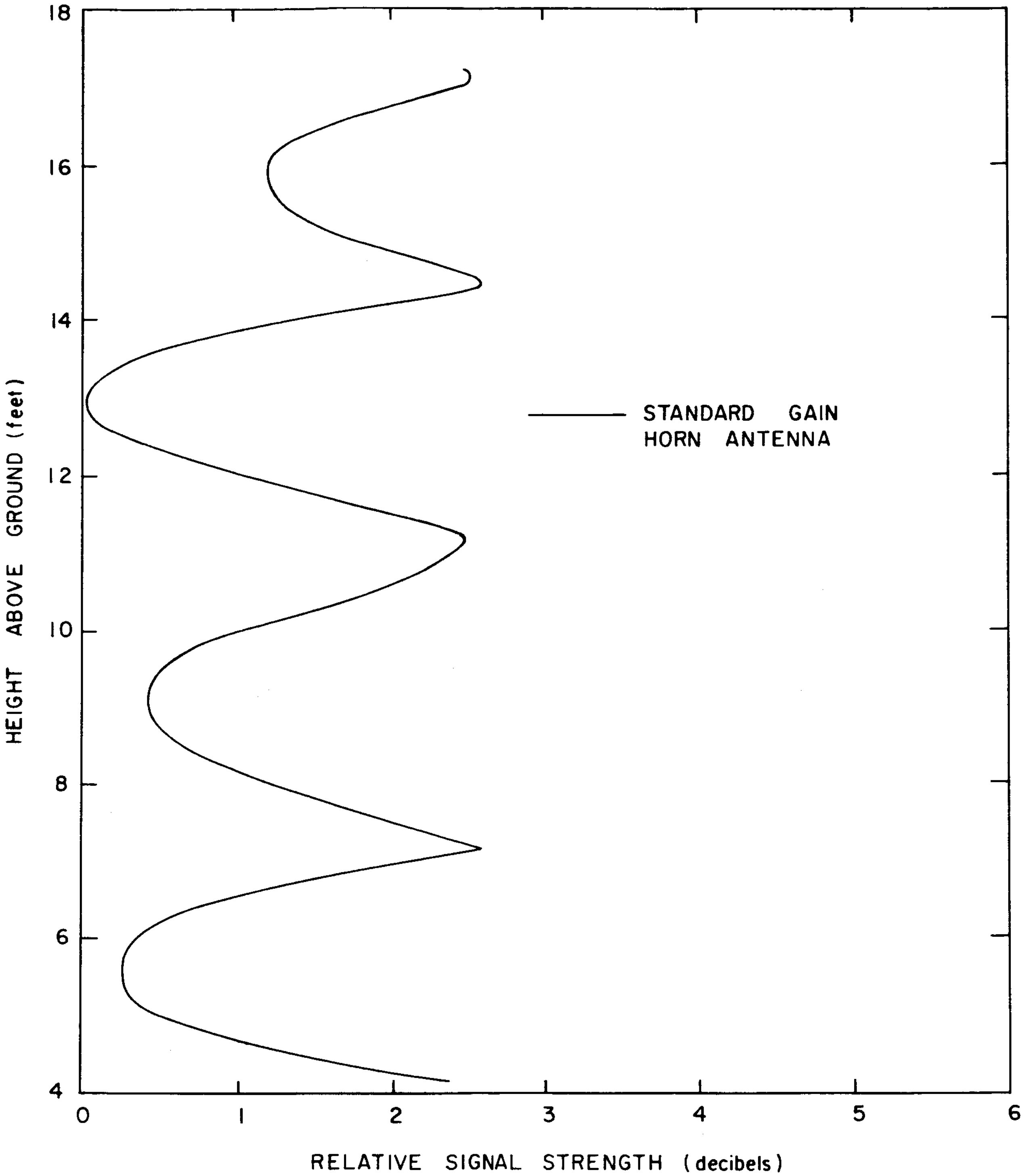
A PROFILE OF THE PROPOGATION PATH BETWEEN THE UNIVERSITY OF TEXAS TOWER AND THE 16 FOOT ANTENNA THAT WAS USED TO EVALUATE THE ANTENNA'S RADIO FREQUENCY CHARACTERISTICS

FIG. 3.



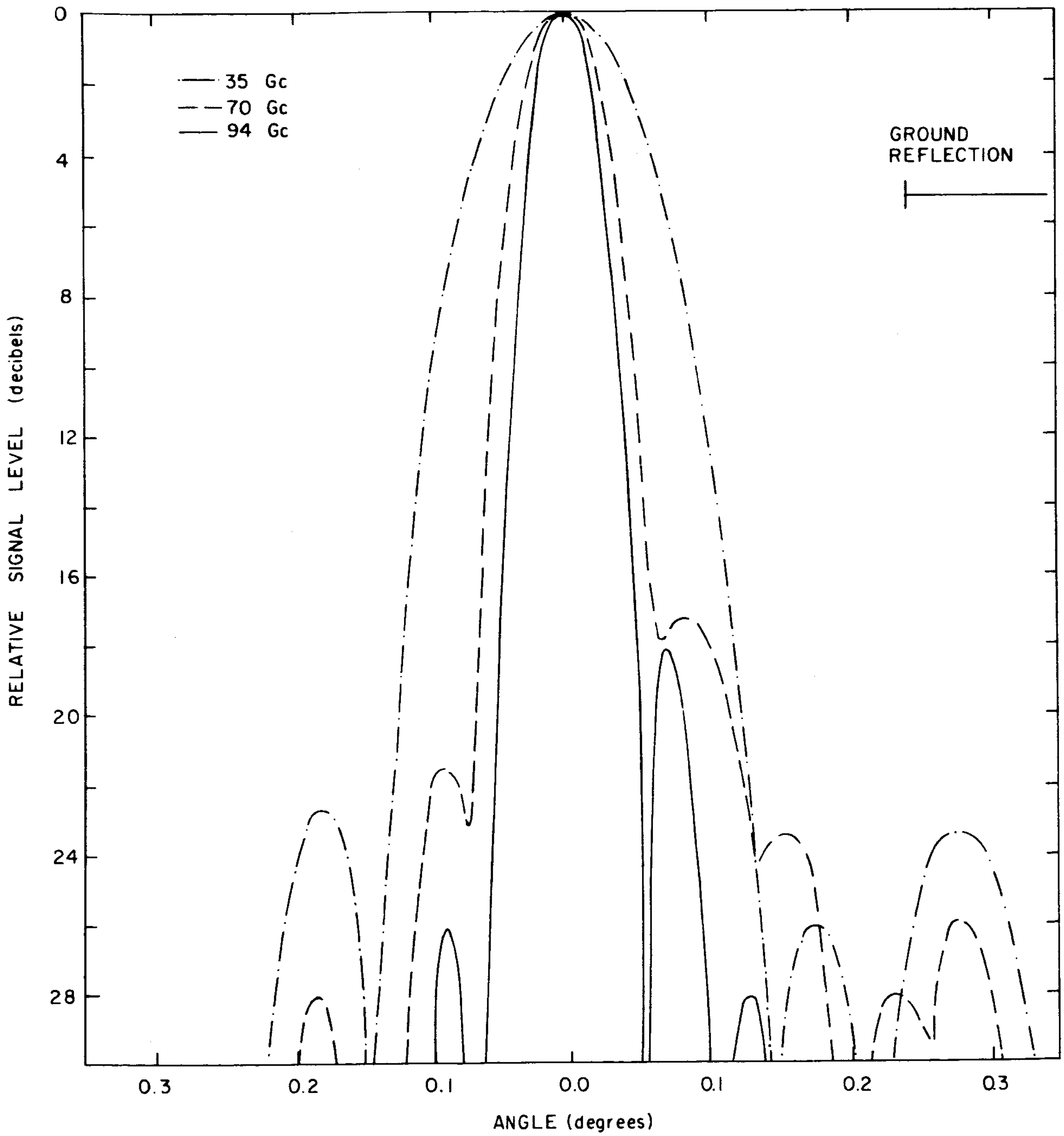
A PHOTOGRAPH OF THE 70 Gc 10 mc/s IF BANDWIDTH RECEIVER RADIOMETER HEAD MOUNTED IN THE SPAR RING OF THE ANTENNA

FIG. 4.



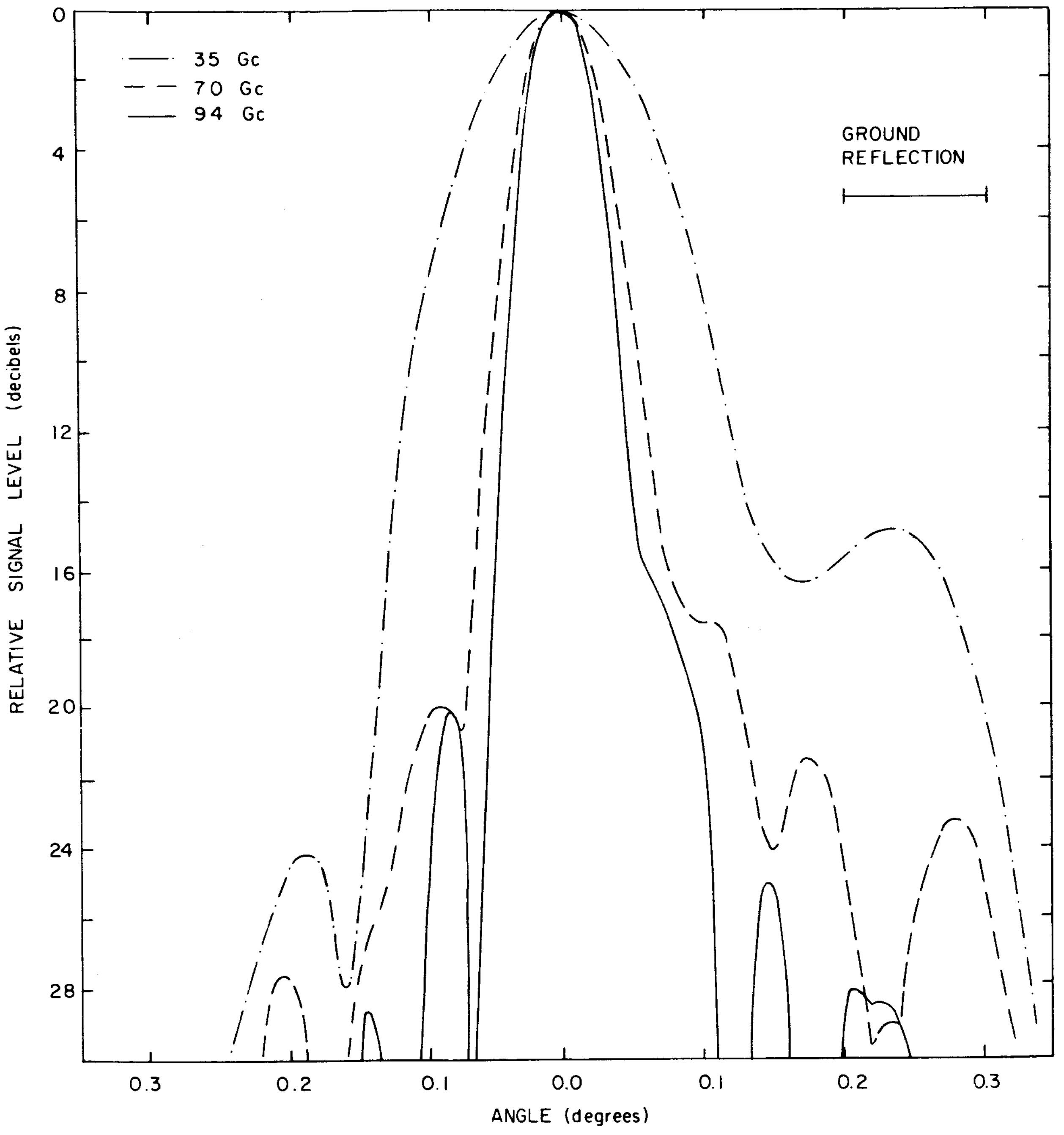
THE VERICAL PROFILE OF 70 Gc SIGNAL STRENGTH
AT THE ANTENNA SYSTEM

FIG. 5.



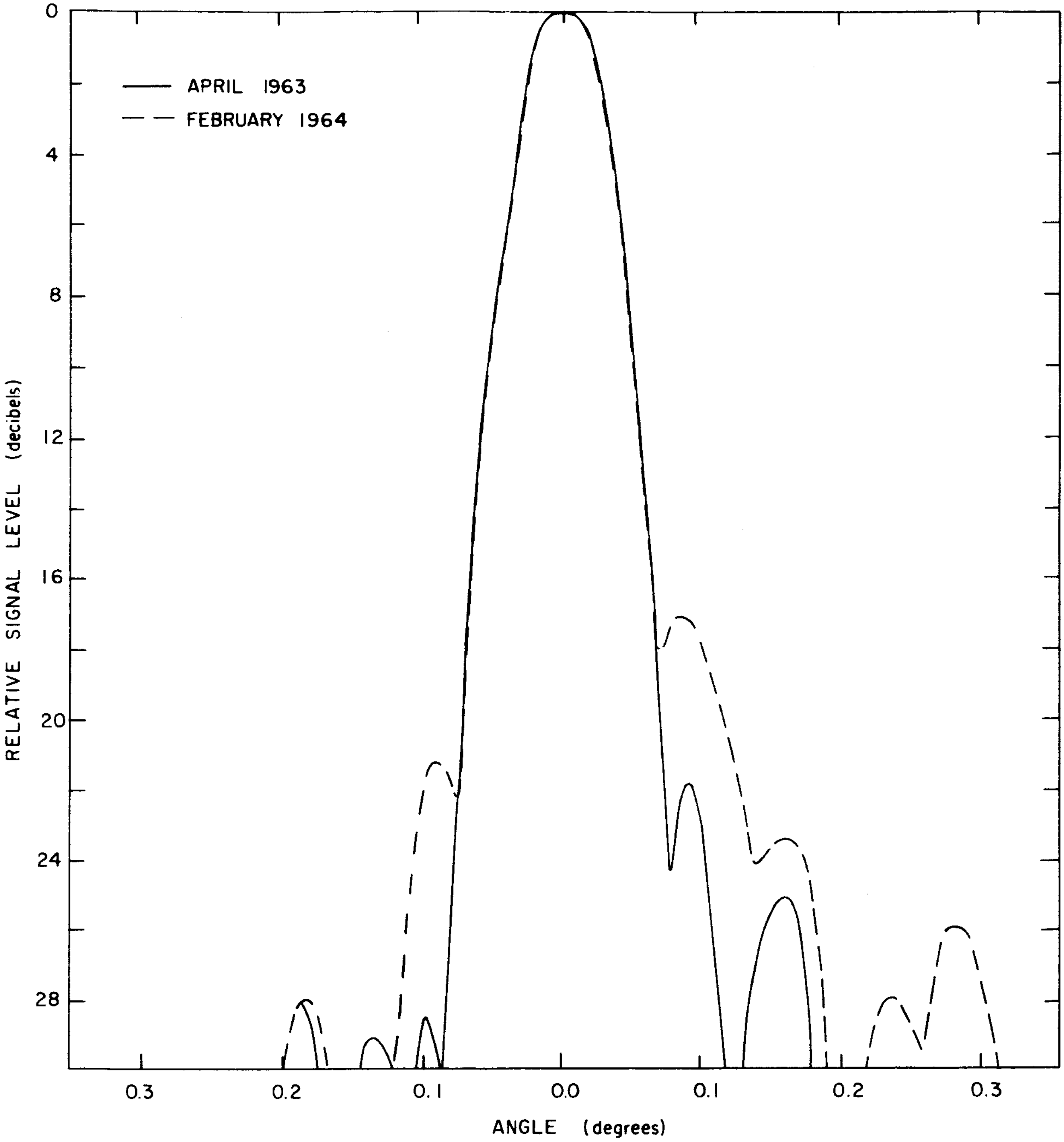
E PLANE (POLAR) 35, 70 AND 94 Gc ANTENNA PATTERNS

FIG. 6.



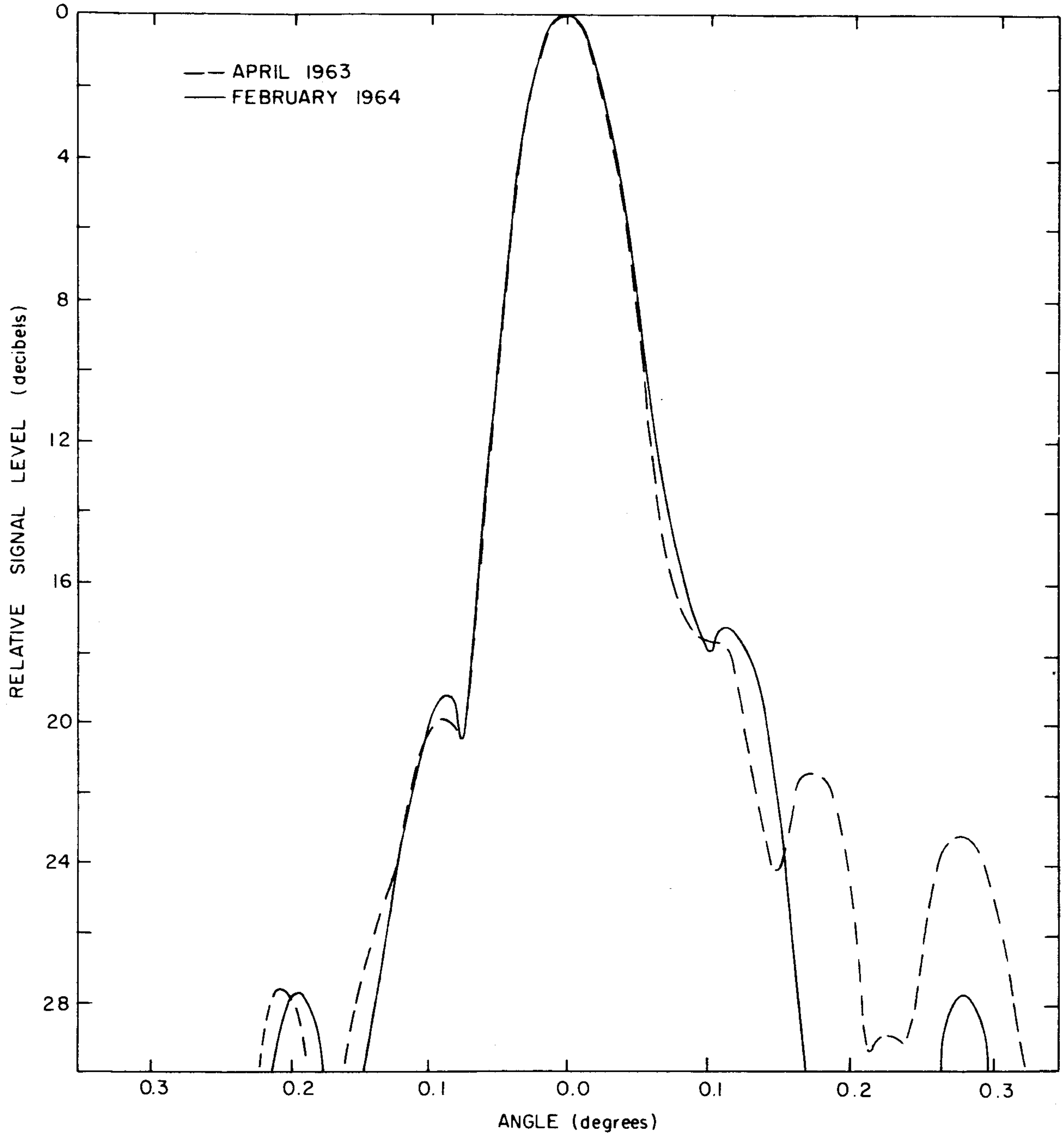
H PLANE (DECLINATION) 35, 70 AND 94 Gc ANTENNA PATTERNS

FIG. 7.



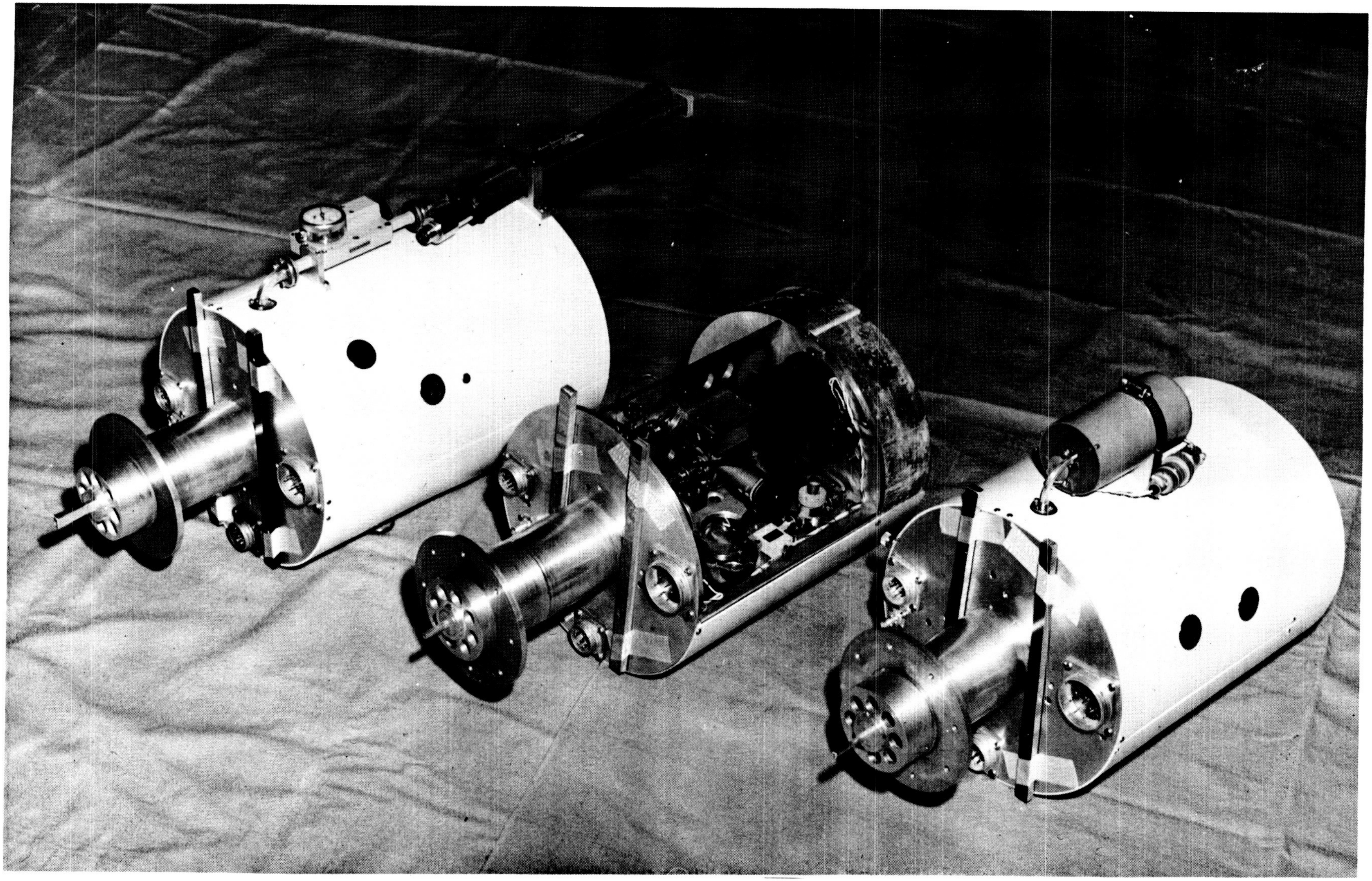
E PLANE 70 Gc ANTENNA PATTERNS MEASURED APRIL 1963 AND FEBRUARY 1964

FIG. 8.



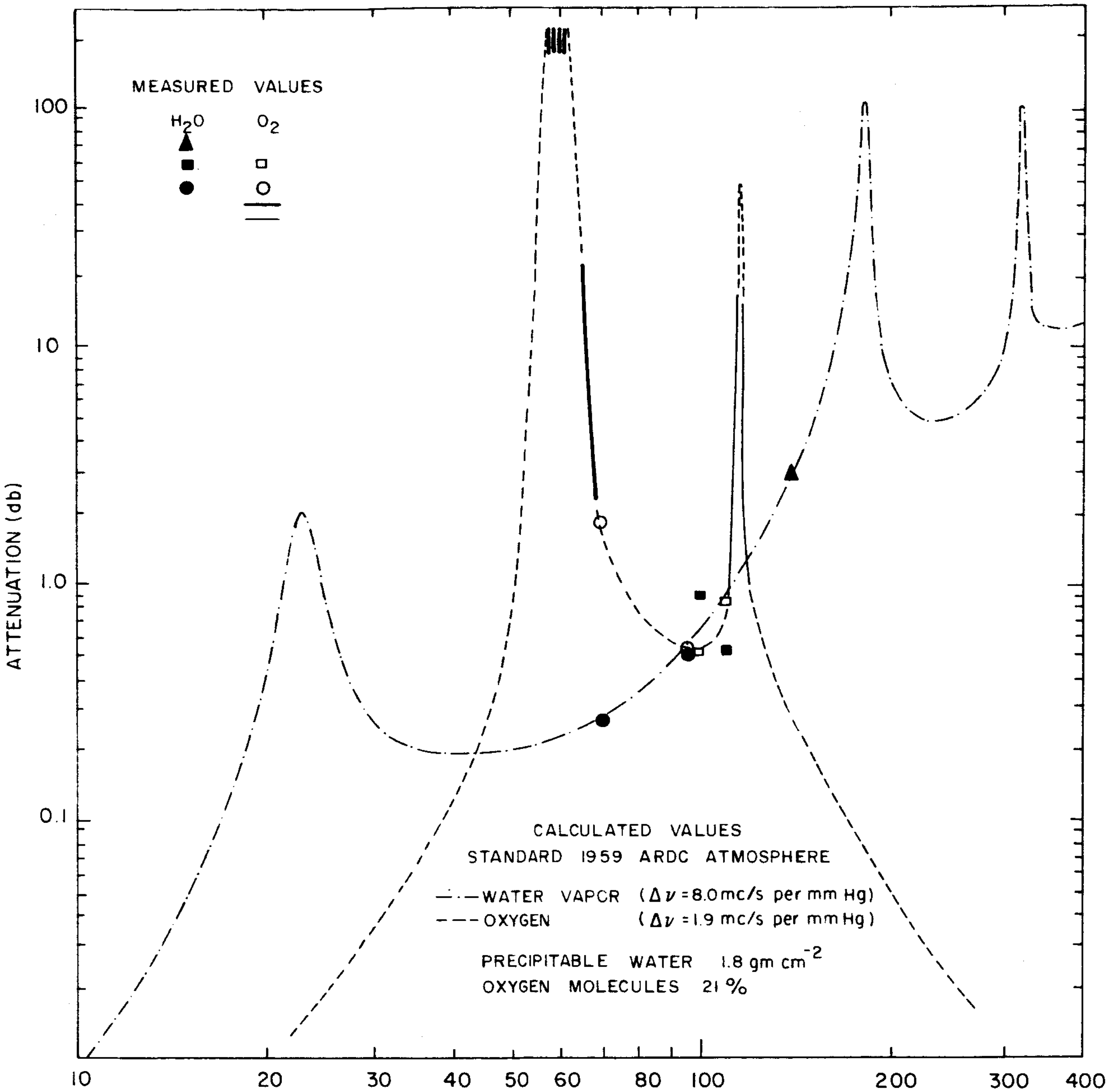
H PLANE 70 Gc ANTENNA PATTERNS MEASURED
APRIL 1963 AND FEBRUARY 1964

FIG. 9.



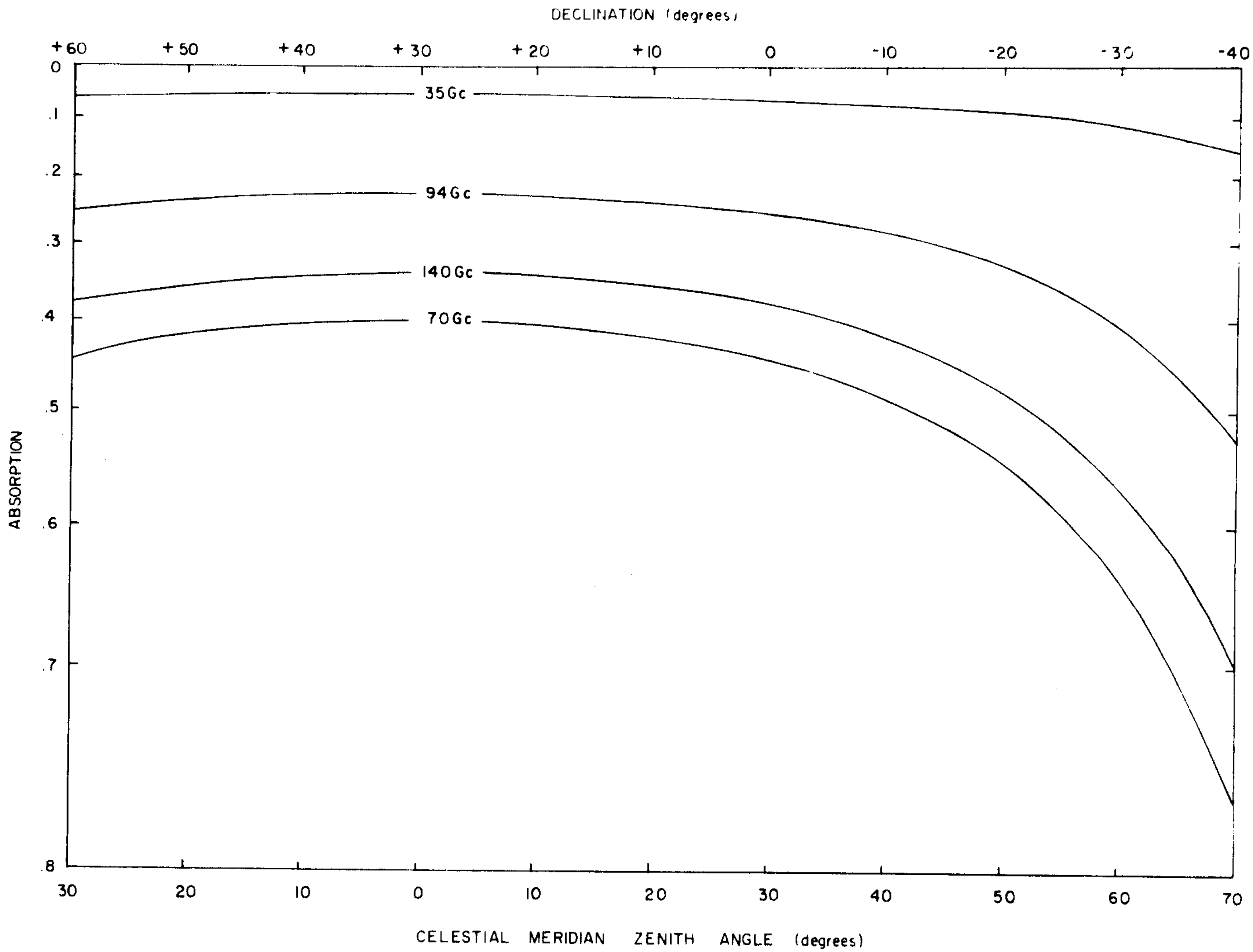
A PHOTOGRAPH OF THE 35, 70, AND 94 Gc 10 mc/s IF BANDWIDTH RADIOMETER HEADS

FIG. 10.



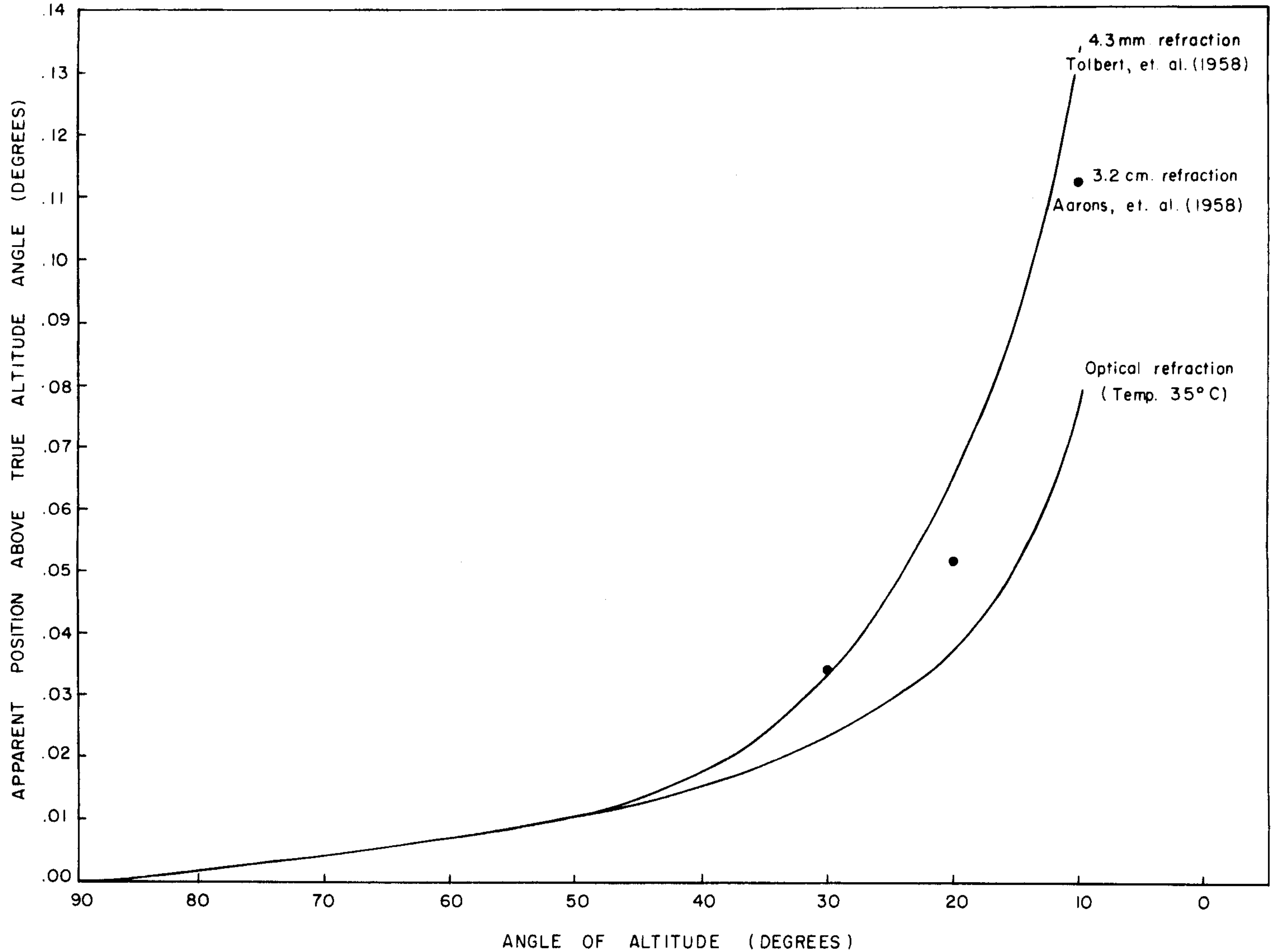
OXYGEN AND WATER VAPOR ZENITH ATTENUATION THROUGH THE EARTH'S ATMOSPHERE BETWEEN THE FREQUENCIES OF 10 AND 400 Gc.

FIG. 11.



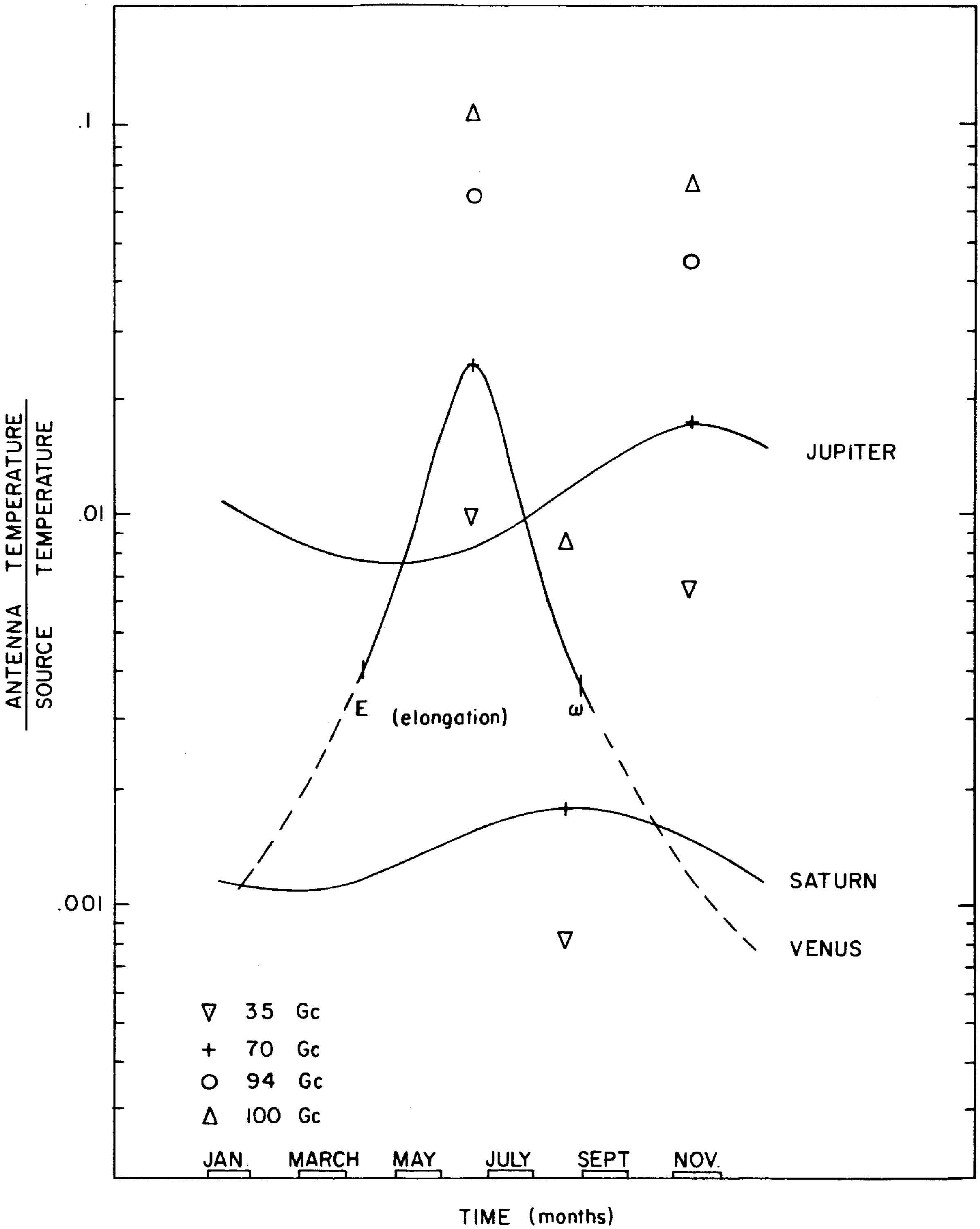
ABSORPTION THROUGH A STANDARD ATMOSPHERE OF 7.5 GRAMS OF WATER VAPOR AT SEA LEVEL AS A FUNCTION OF ZENITH ANGLE AND MERIDIAN DECLINATION ANGLE

FIG. 12.



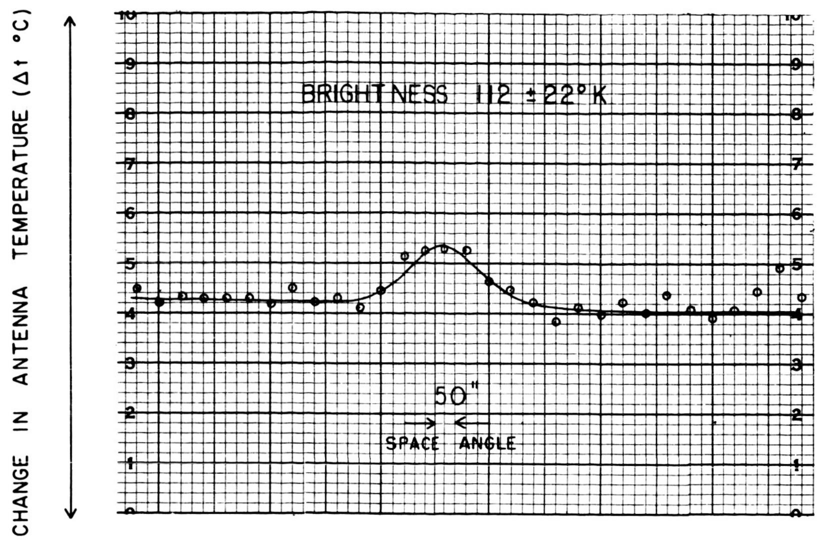
THE 70 Gc REFRACTION DURING THE SUMMER MONTHS AT THE LOCATION OF THE MILLIMETER TELESCOPE

FIG. 13.

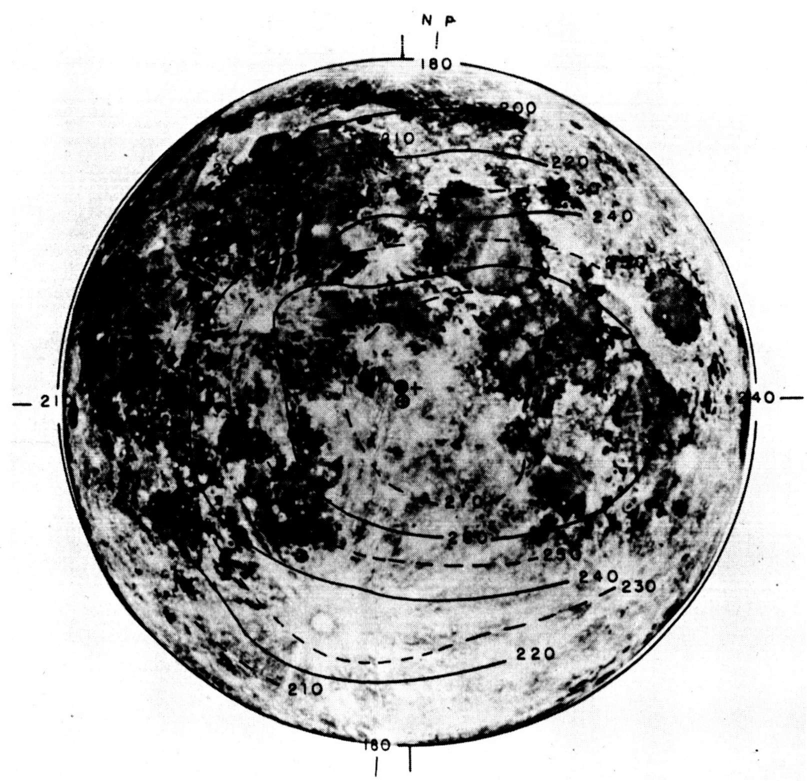


CALCULATED ANTENNA TEMPERATURE AS A FRACTION OF PLANET TEMPERATURES DURING CALENDER 1964

FIG. 14.



HOUR ANGLE SCANS OF JUPITER (OCTOBER 1963)



BRIGHTNESS CONTOURS (°K) FOR 100% ILLUMINATION
+ SELENOGRAPHIC COORDINATE LAT. 0° LONG. 0°
● SUB SOLAR POINT
⊕ SUB TERRESTRIAL POINT

LUNAR RADIATION TEMPERATURE CONTOURS

AN EXAMPLE OF 70 Gc PLANETARY AND LUNAR BRIGHTNESS TEMPERATURE MEASUREMENTS

FIG. 15.

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